PROCESS FOR IMPROVING THE HOT WORKABILITY OF A CAST SUPERALLOY INGOT

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[0001] This application claims the benefit of the filing date of U.S. Provisional Patent Application No. 60/429,209 filed November 26, 2002.

Field of the Invention

[0002] This invention relates to processes for hot working cast Ni, Fe and Co base alloy ingots, and in particular to a process for preparing a cast Ni base superalloy ingot so that it can be readily hot worked.

Background of the Invention

[0003] Superalloys are relatively difficult to hot work compared to stainless and carbon steel alloys. Because they are highly alloyed and have complex microstructures, superalloys are generally hot worked over a relatively narrow temperature range to avoid cracking. Specialty alloy producers and forging shops that regularly hot work superalloys have developed practices, often proprietary, to improve the hot workability of the superalloy articles they produce. These techniques typically seek to reduce the amount of thermal loss from the workpiece to its surroundings, especially for the workpiece surfaces that make contact with the forging dies. These practices have encompassed the following techniques: 1) using specially designed preheaters to heat the forging dies to a desired preheating temperature prior to forging; 2) using isothermal forging, where the workpiece and the dies are heated to a desired working temperature and kept at this temperature during the forging operation; 3) placing insulation on the dies or the workpiece to reduce heat losses from the workpiece surface to the forging dies; 4) physically attaching carbon steel plates directly to the workpiece and heating the ingot-plate assembly to the desired forging temperature; or 5) attaching

separately heated low carbon steel plates onto the workpiece or the forging dies to reduce the heat loss at the die contact area.

[0004] The hot working of difficult to work alloys, such as high speed steels and Co-Cr-Mo alloys, has been facilitated by providing the alloy in the form of prelate metal powder that has been hot isostatically pressed to substantially full density inside of a carbon or stainless steel canister. The canister serves as the pressure-transmitting medium through which the powder is consolidated during hot isostatic pressing. The canister also benefits the hot workability of the metal powder by limiting heat loss from the metal powder during subsequent hot working of the HIP'd powder. Further, the canister also provides a ductile surface zone that is less prone to checking and cracking. The concept of hot working a HIP'd metal powder inside a canister has been found to improve the hot workability of these otherwise difficult to hot work alloys.

[0005] More recently a need has arisen for producing large diameter (nominal 6-10 inch round) billets of cast superalloys, such as Super WASPALOY, René 41, and PYROMET® 720 alloys, which are used for aerospace applications. The hot working of these materials is difficult because the alloys have a very narrow hot working temperature range and the ingot/billet cools off rapidly during hot working. This results in significant cracking of the billet during forging, particularly at the longitudinal surfaces and end faces of the workpiece. This cracking can be so severe that the entire ingot becomes unusable and must be scrapped. The inability to consistently hot work the superalloy billet without significant damage from cracking or checking results in significant waste of expensive material and a loss of productivity. The known processes for improving the hot workability mentioned above have proved ineffective in resolving the problems associated with the hot working of large billets of difficult to hot work superalloys.

Summary of the Invention

[0006] In accordance with a first aspect of this invention, there is provided a process for preparing a superalloy ingot for hot working. The process includes the steps of providing a cast ingot of a superalloy and inserting the ingot into a metal canister that is

adapted to encapsulate it. The ingot is positioned within the steel canister so as to provide an annular space and end spaces between the ingot and the canister. Metal powder is filled into the annular space and end spaces between the ingot and the canister. The metal powder is selected to readily bond with the surfaces of the ingot and the canister. The canister is then closed (except for an evacuation tube) with the ingot and the metal powder inside. Gas and moisture are evacuated from the interior of the canister and the canister is then sealed. The canister with the ingot and the metal powder inside is hot isostatically pressed to produce an ingot assembly having a cladding formed about the entire ingot.

[0007] In accordance with a second aspect of this invention, there is provided a process for hot working a superalloy ingot. The process includes the steps of providing a cast ingot of a superalloy and inserting the ingot into a metal canister that is adapted to encapsulate it. Metal powder is initially poured into the bottom of the steel canister to form a layer that separates the ingot from the canister bottom. The ingot is then positioned within the steel canister so as to provide an annular space between the ingot and the canister. Metal powder is filled into the annular space. The metal powder is selected to readily bond with the surfaces of the ingot and the steel canister. The canister is closed except for an evacuation tube. Gas and moisture are evacuated from the interior of the canister through the evacuation tube, which is subsequently sealed. The canister with the ingot and the metal powder inside is hot isostatically pressed to form an assembly having a cladding formed about the entire ingot. The assembly is then heated to a temperature suitable for hot working the superalloy and then the assembly is hot worked to a desired shape and size.

[0008] In accordance with a further aspect of this invention, there is provided an assembly for facilitating the hot working of a superalloy ingot. The assembly includes an ingot formed of a superalloy, a layer of cladding surrounding the ingot, and a layer of consolidated metal powder disposed between the ingot and the cladding and bonded to the ingot and the cladding layer.

Brief Description of the Drawings

[0009] The foregoing summary as well as the following detailed description of the process according to the present invention will be better understood when read in connection with the appended drawings wherein:

[0010] **Figure 1** is a perspective view of a canister/ingot assembly used in the process according to this invention;

[0011] **Figure 2** is an elevation view of a cross section of the canister/ingot assembly shown in **Figure 1** as viewed along line **2-2** therein;

[0012] **Figure 3** is a perspective view of an alternative embodiment of a canister/ingot assembly used in the process according to this invention; and

[0013] **Figure 4** is an elevation view of a cross section of the canister/ingot assembly shown in **Figure 3** as viewed along line **4-4** therein;

Detailed Description

[0014] The process according to the present invention preferably uses a generally cylindrical steel canister with a dome top to encapsulate an ingot of a superalloy. Here and throughout this specification the term "superalloy" means an Fe-base, Co-base, and/or Ni-base alloy that contains chromium for resistance to oxidation and hot corrosion, and which may contain additional elements for providing high strength at elevated temperatures. The canister is preferably formed from low alloy or mild steel, although stainless steel could be used. An intermediate layer of metal powder is filled into the space between the steel canister and the cast superalloy ingot. The carbon steel canister provides a basic mold to contain the powder and the ingot. The canister is considered to be disposable because it is expected to scale heavily during the long time, high temperature heating cycles the ingot will undergo during the hot working operation. The canister can be readily formed from commonly available steel pipe and top dome that have an internal diameter that is larger than the largest diameter of the as-cast superalloy ingot. When required, a tapered canister could be used, but such a canister must be specially rolled and welded to fit the tapered ingot. Preferably, the canister is thin-walled, i.e., about 1/4-3/8 inch thick.

[0015] The metal powder is preferably made from a stainless steel alloy such as Type 304 or Type 316 stainless steel. Alternatively, the metal powder can be a superalloy powder of the same or similar composition as the superalloy ingot, a non-ferrous alloy such as an 80Ni-20Cr alloy, or a mixture of either or both of those alloys with or without the stainless steel powder. Stainless steel powder has a lower thermal conductivity than carbon steel and provides thermal insulation at the surface of the cast ingot during hot working. Because of its composition the stainless steel powder layer does not scale as heavily as the steel canister. Consequently, a significant amount of the stainless steel will remain on the surface of the cast ingot during the thermal and deformation cycles undergone by the ingot. Readily available stainless steel powder can be used to fill the annular spacing between the ingot and the steel canister. Austenitic stainless steel powders, such as Type 304 and Type 316L powders, are ductile and do not undergo a hardening phase transformation that could cause cracking during the hot working process. Prior to being used in this process, the metal powder is preferably baked at about 250°F to remove any moisture therefrom.

[0016] The canister is sized to accommodate a powder layer that is about ½ inch to about 7/8 inch thick along the length of the ingot and at least about 3/4 inch to 1 inch thick at the ends of the ingot. Although thicker powder layers could by used, a thinner powder layer permits the as-consolidated powder to flow more like the core ingot material, particularly at the ends of the canister/ingot assembly. This permits the ingot manipulator to grab more of the ingot material during hot working operations, thereby avoiding delamination of the cladding from the ingot.

[0017] The superalloy ingot that is to be used is prepared to remove virtually all traces of surface porosity, oil, grease, and oxidation from all of its surfaces. This is done typically by Tysaman grinding of the ingot's longitudinal surface, hand grinding of the ingot ends, and hand wiping of all of the ingot surfaces with solvent, such as reagent grade acetone. These surface cleaning operations are performed to foster bonding between the ingot and the metal powder during HIP'ng. The ends of the ingot are also tapered to remove sharp edges that could cut through the consolidated metal powder during forging. The ingot is also preferably baked out at about 250°F to

remove any residual solvent and moisture on the ingot surface prior to insertion into the steel canister.

[0018] The preferred procedure for forming the ingot/canister assembly is to place a layer of the powder into the canister at one end thereof. The ingot is then placed partially within the bottom part of the steel canister so as to provide an annular space between all other surfaces of the ingot and the steel canister. Metal powder is filled into the annular space up to within about 4 inches of the top of the bottom section of the canister. The metal powder is selected to readily bond with the surfaces of the ingot and the steel canister. The top part of the canister is then positioned over the top end of the ingot and an argon purge gas is applied through a tube inserted through the top of the top part of the canister to remove air from the interior of the canister. When there is essentially no air inside the canister, the top part of the canister is welded onto the bottom part of the canister, which seals the canister, except for a powder fill hole located in the top part of the canister. Additional powder is then filled into the top section of the canister, filling the annular spacing between the top and side of the ingot and the interior of the canister. Vibration filling of the powder is preferred to obtain the best fill density. A metal closure plate, containing an evacuation tube is then placed onto and welded to the top part of the canister, sealing the canister except for the evacuation tube. A stainless steel mesh screen, typically -325 mesh, is welded to the bottom end of the evacuation tube in the disk opening to prevent powder from being pulled out of the canister during a subsequent evacuation step. Gas and moisture are then evacuated from the interior of the steel canister by vacuum hot out-gassing the canister and its contents through the evacuation tube, which is subsequently sealed.

[0019] Referring now to Figures 1 and 2, there is shown an arrangement of a canister/ingot assembly used in the process according to this invention. The canister/ingot assembly 50 includes an ingot 10 of a superalloy such as PYROMET 720 or Super WASPALOY. The ingot 10 is disposed in a steel canister 20 and a layer 30 of stainless steel powder is provided between the ingot 10 and the canister 20 along the length and ends thereof. An evacuation tube 40 is welded into a central opening in the

top end 22 of the canister 20. As described above, a fine mesh (typically -325 mesh) screen 60 is welded to the end of tube 40 that is welded to the canister top.

[0020] Referring now to Figures 3 and 4, there is shown a preferred arrangement of a canister/ingot assembly used in the process according to this invention. The canister/ingot assembly 350 includes an ingot 310 of a superalloy. The ingot 310 is disposed in a steel canister 320 having a domed top portion 322 and a generally cylindrical bottom portion 324. In this arrangement, the ingot 310 is longer than the bottom portion 324. The ingot 310 is chamfered or tapered at the end proximate the domed top portion 322 to remove a sharp edge that could cut through the consolidated metal powder and the canister during hot working. A layer 330 of stainless steel powder is provided between the ingot 310 and the canister 320 along the length and ends thereof. An evacuation tube 340 is welded into a central opening in the domed top portion 322 of the canister 320. As described above, a fine mesh screen 360 is welded to the bottom end of tube 340.

[0021] When the canister/ingot assembly is fully assembled, it is placed into a furnace or oven. The evacuation tube is connected to a vacuum pump. The canister/ingot assembly is then hot outgassed to remove substantially all moisture and oxygen from the metal powder. To that end, the canister/ingot assembly is heated at an elevated temperature, preferably about 250-400°F while a vacuum of less than about 200 microns of Hg is applied to the interior of the assembly. The canister/ingot assembly is maintained at the temperature and vacuum conditions until the pressure inside the canister reaches a minimum, at which time the out gassing step is terminated. The evacuation tube is then hot crimped, sealed and cut and the assembly is hot isostatically pressed (HIP'd) to substantially full densify the metal powder. A HIP'ng cycle in the temperature range of about 2000-2350°F and about 15ksi for about 4-8 hours is preferred to achieve the desired degree of densification when austenitic stainless steel powder is used. HIP'ng not only consolidates the metal powder, but also causes it to bond to both the steel canister and to the superalloy ingot. Additionally, during the HIP'ng step, the powder is forced into any porosity on the surface of the ingot, thereby eliminating such porosity as a delamination or crack initiation source during subsequent

hot working. It is believed that the sealing of the ingot surface porosity further improves the hot workability of the ingot. Although HIP'ng is a relatively expensive processing technique, it is believed that the increase in product yield obtained from the improved hot workability will offset the cost of HIP'ng. When necessary other HIP'ng cycles could be used.

[0022] At the completion of the HIP'ng cycle, the canister/ingot assembly is an integral body comprising the superalloy and a cladding composed of the steel canister and the consolidated metal powder interlayer. The clad ingot is then heated and hot worked in the usual manner to make a desired product form such as bar or billet.

[0023] The ingot/cladding assembly is readily hot worked, such as by upsetting and press forging, according to known thermo-mechanical processing techniques. When the desired billet size and shape are obtained, any cladding remaining on the superalloy material is removed, preferably by a machining or grinding operation.

[0024] By way of example, an ingot of PYROMET 720 steel alloy was prepared and clad as described above in accordance with the process of this invention. The clad ingot was then upset and drawn on a forging press. No canister delamination was noted during these operations. The clad ingot was subjected to a second heating and forging cycle. Inspection of the forged billet after the second cycle showed essentially no surface or end cracking or canister delamination occurred (i.e. only minor local cracking or canister delamination was observed). Subsequent to the second hot working operation, the cladding was ground off the longitudinal surface of the forged billet and the billet was then processed to a nominal 6" rd. bar.

[0025] The terms and expressions which have been employed herein are used as terms of description, not of limitation. There is no intention in the use of such terms and expressions of excluding any equivalents of the elements, features, or steps shown and described or portions thereof; however, it is recognized that various modifications are possible within the scope of the invention claimed.